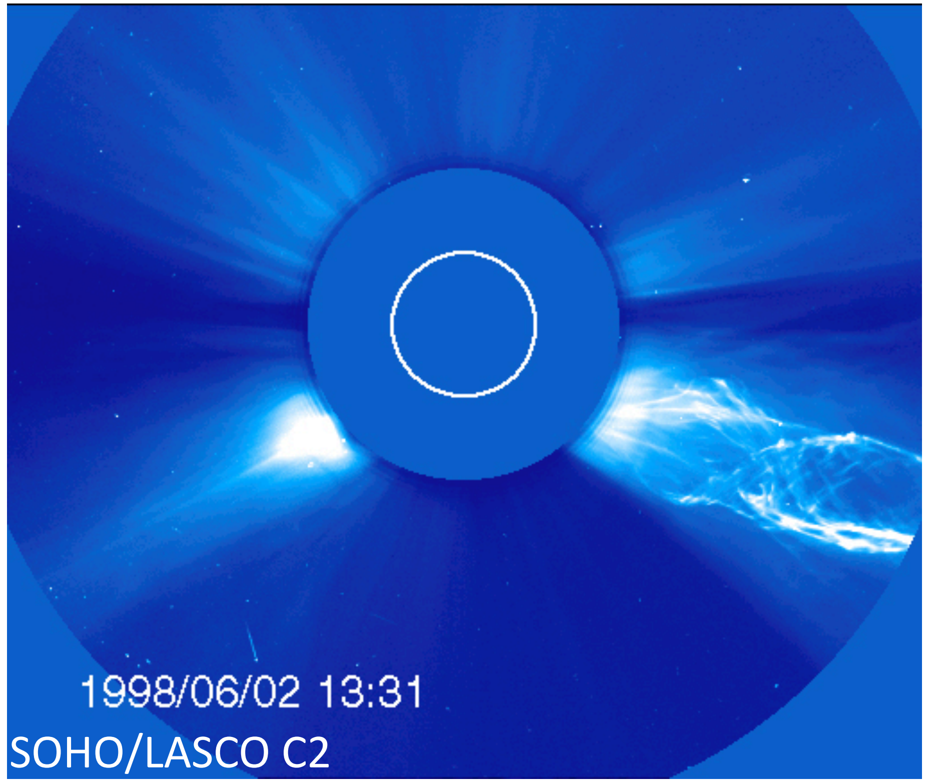
CME Analysis with StereoCAT for Space Weather: Part 1

Community Coordinated Modeling Center



Acknowledgements:
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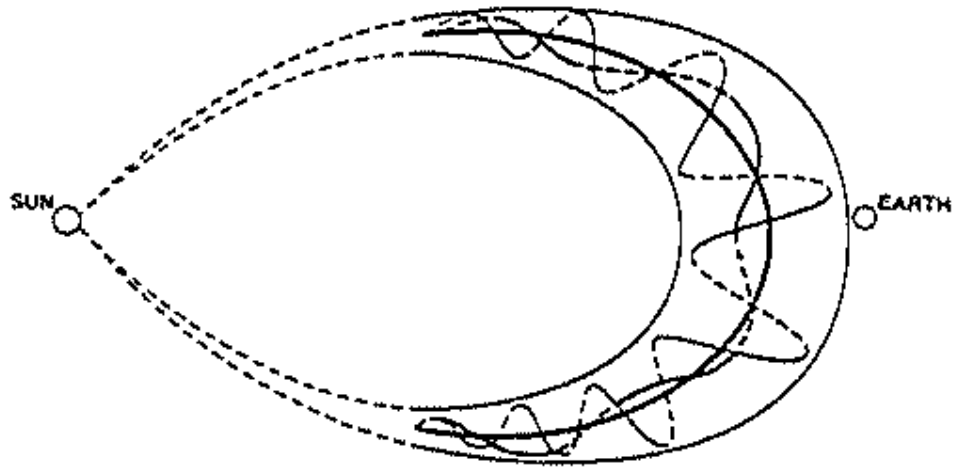
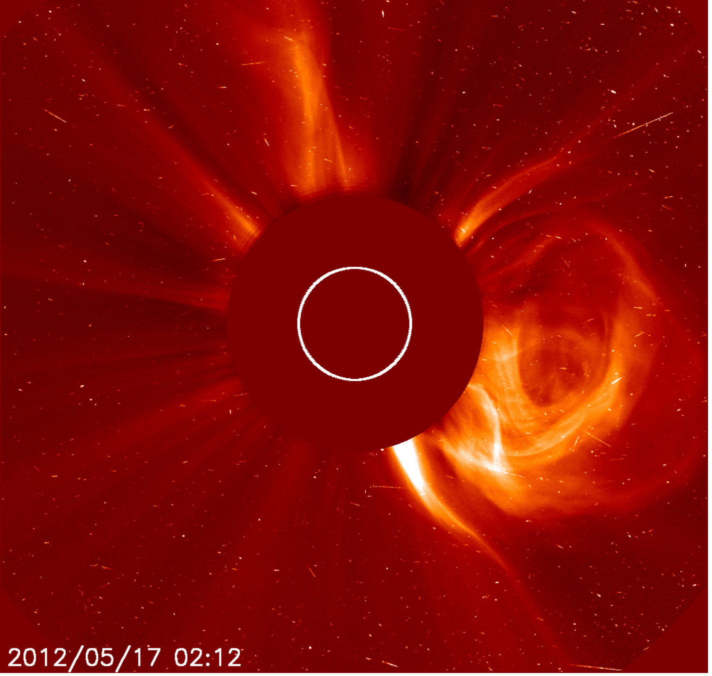
Coronal Mass Ejections are important drivers of space weather activity. Their shocks can accelerate particles (SEPs).
Earth directed CMEs (CMEs that propagate towards Earth's location) produce the majority of geomagnetic storms.



Purpose of this lesson: Learn how to measure the kinematic properties of CMEs (CME parameters) and determine their qualitative features.

Motivation: CME parameters are used as initial conditions of CME propagation models. These models are used to estimate the CME path and arrival time at various locations.

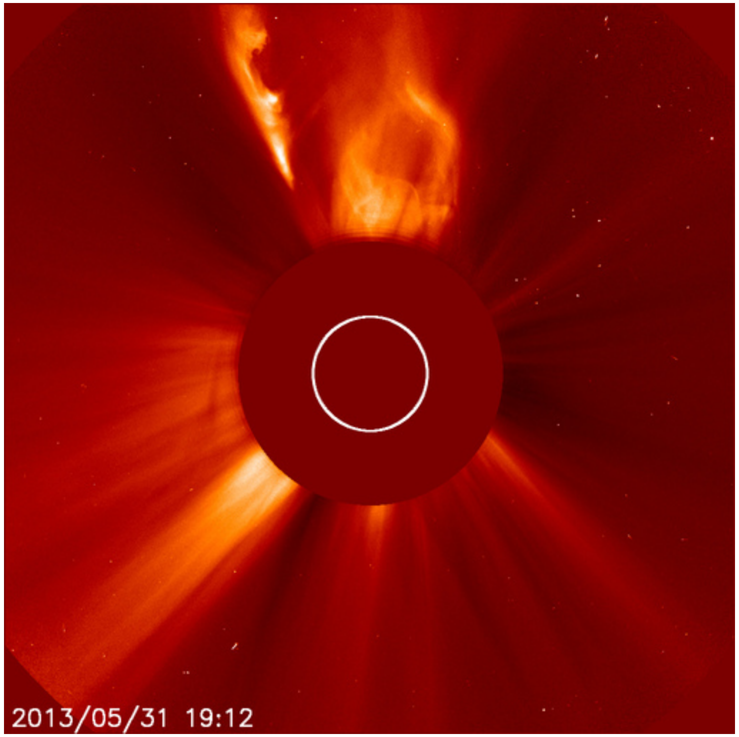


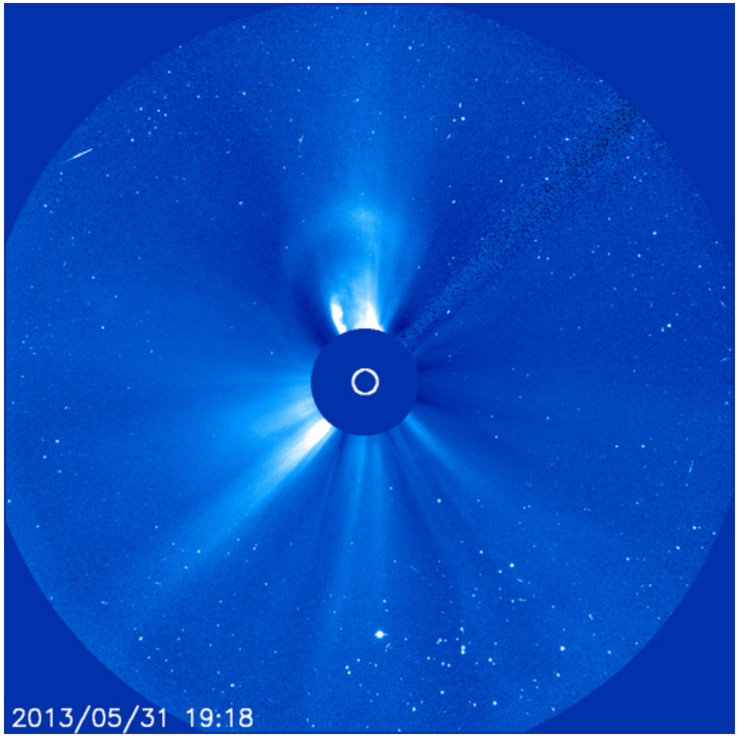
Coronal Mass Ejections

- Removal of magnetic field and mass from the solar corona – clouds of magnetized plasma
- 10^{12} – 10^{13} kg mass
- CMEs originate from closed magnetic field regions, such as active regions, filament regions.
- Appear as bright loops moving away from sun in **coronagraphs**

Coronagraphs block out the direct light of the Sun in order to view the faint corona.

They are white light images, line of sight integrated scattered light from the Sun from the coronal electrons (**Thomson scattering**). You are seeing the CME projected onto the **plane of the sky**

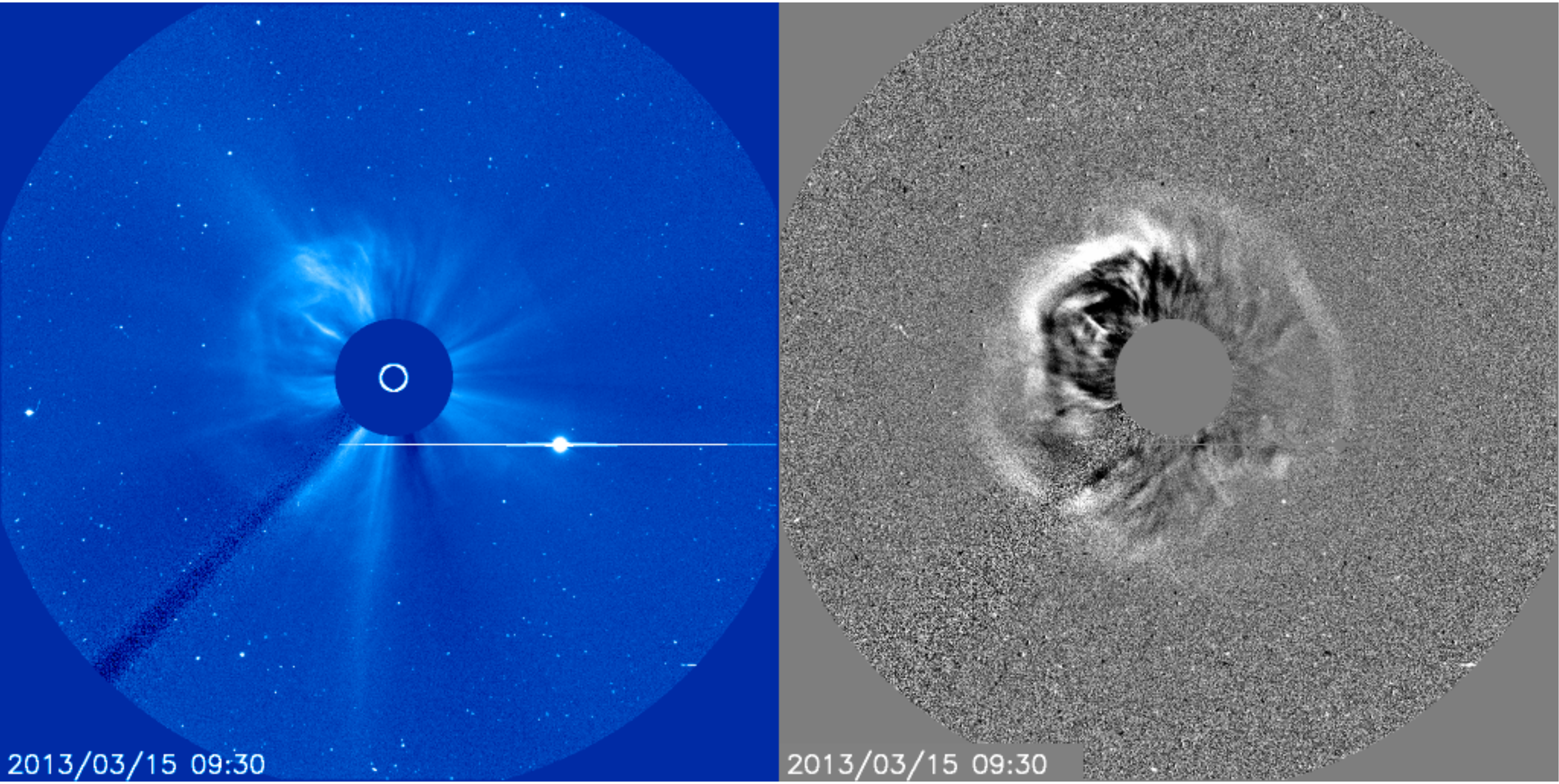




The **plane of sky** is the instrument image plane seen here

Example [movies]

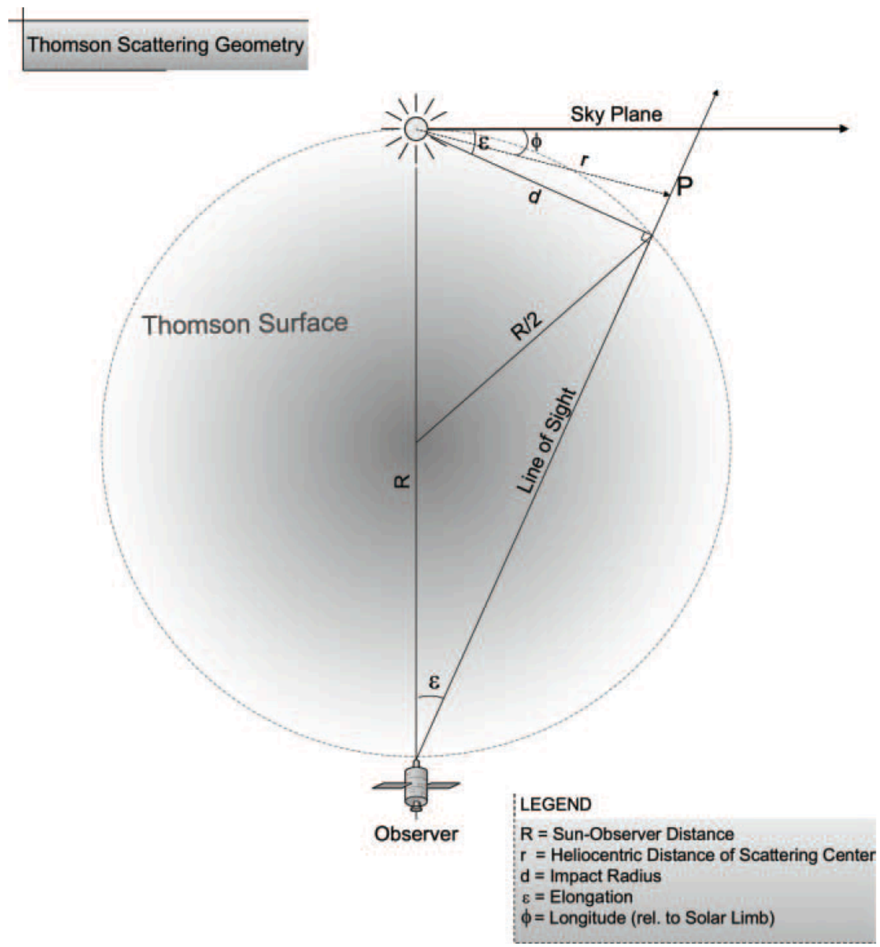
Halo CMEs are CMEs that appear to surround the occulting disk of the coronagraph. The CME can originate from the front or back side of the Sun, and therefore are travelling either towards or away from the observer.



Due to scattering and projection, the CME sides or flanks are detected in these images

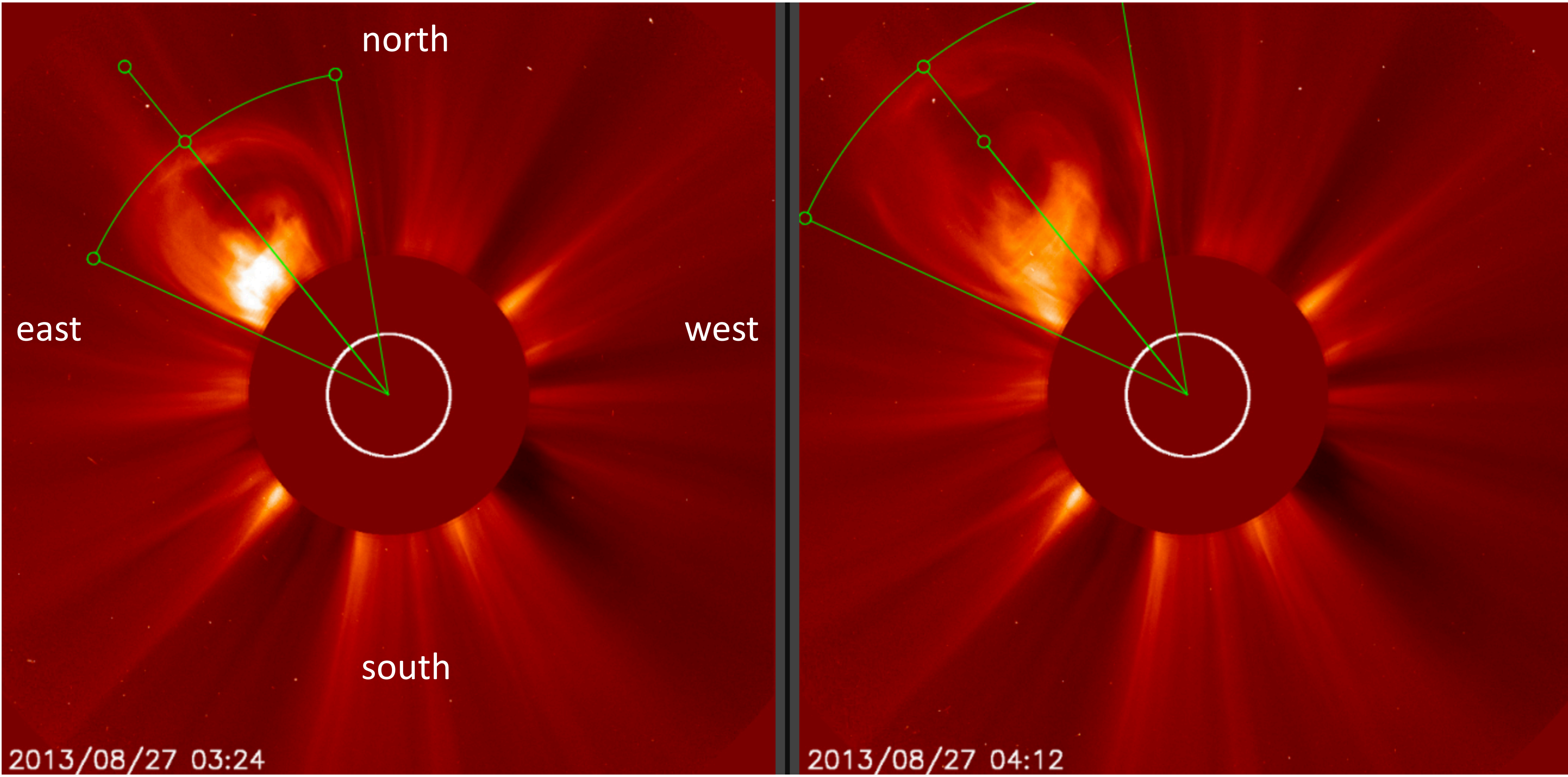
How CMEs appear in **coronagraphs** depend on projection effects and Thomson scattering amplitudes *(more on this in part 2)*.

* In general, close to the Sun, CMEs which are far from the plane of sky are less visible, but the CME width should be considered.
* The most brightness is visible near "Thomson surface".



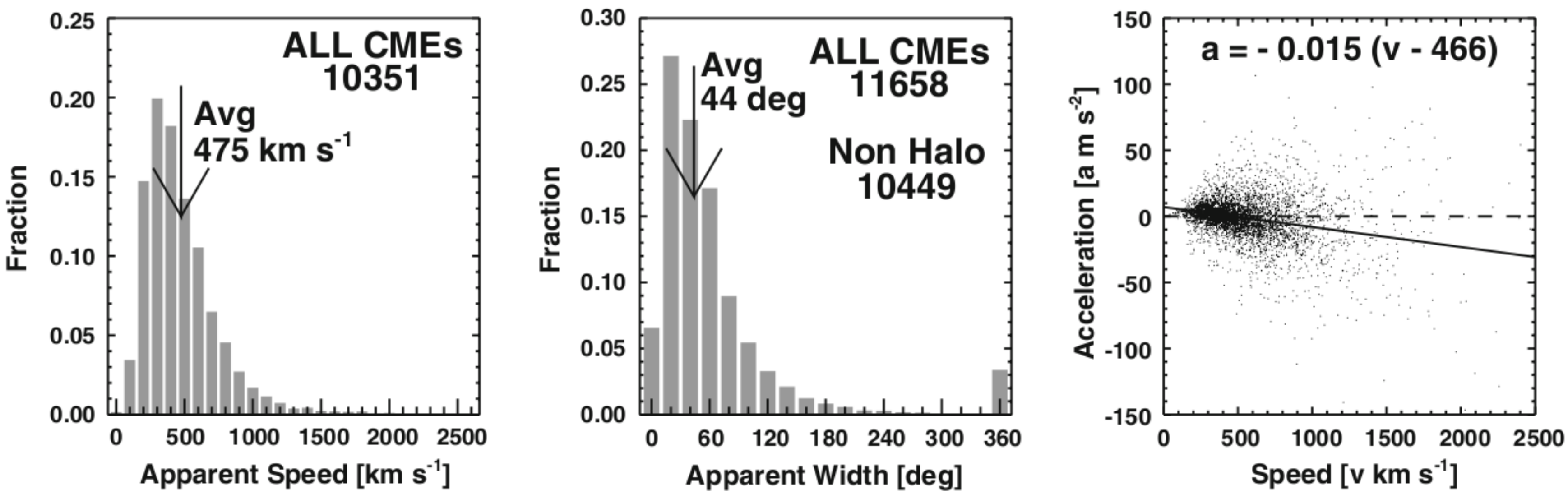
Vourlidas & Howard, 2006

With **coronagraph** data you can measure the leading of the CME at different times. From this you can determine the "**plane-of-sky**" speed by measuring the position of the **leading edge** of the CME at two times. By using **coronagraphs** on various spacecraft, you can get a measurements of this projected speed from various viewpoints.



Coronal Mass Ejection Parameters

- Average speed ~475 km/s, width~44 deg

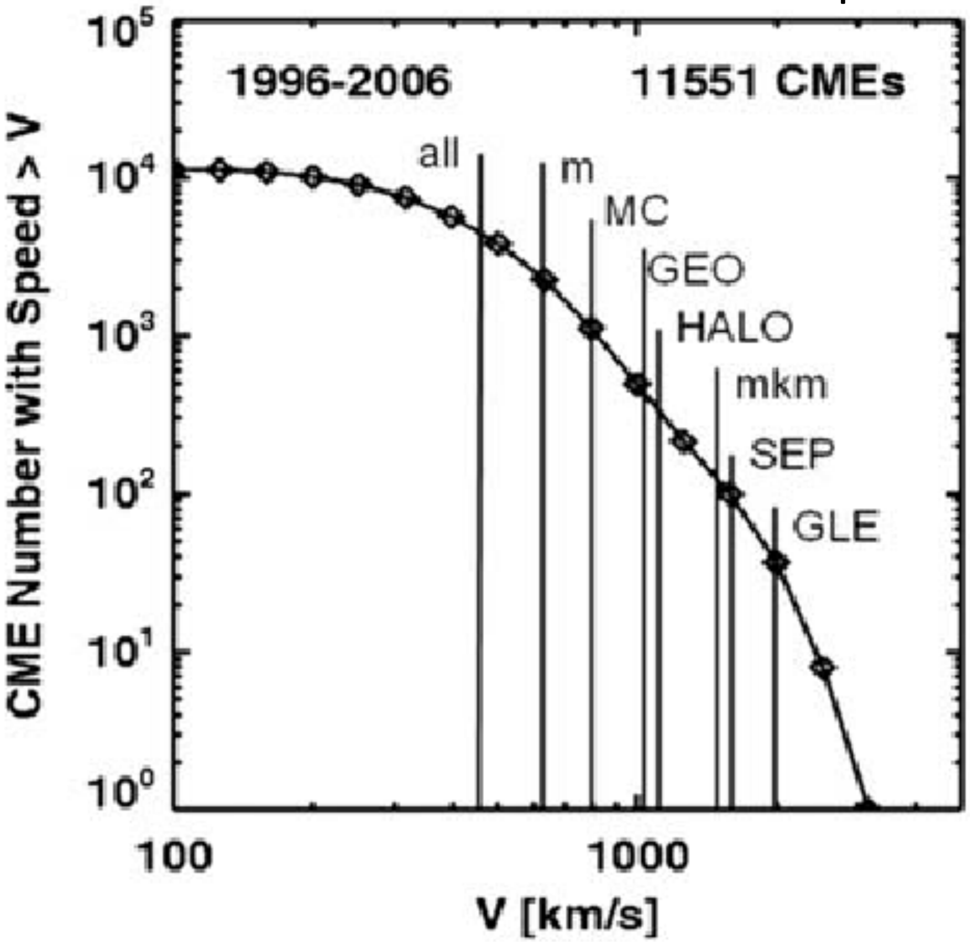


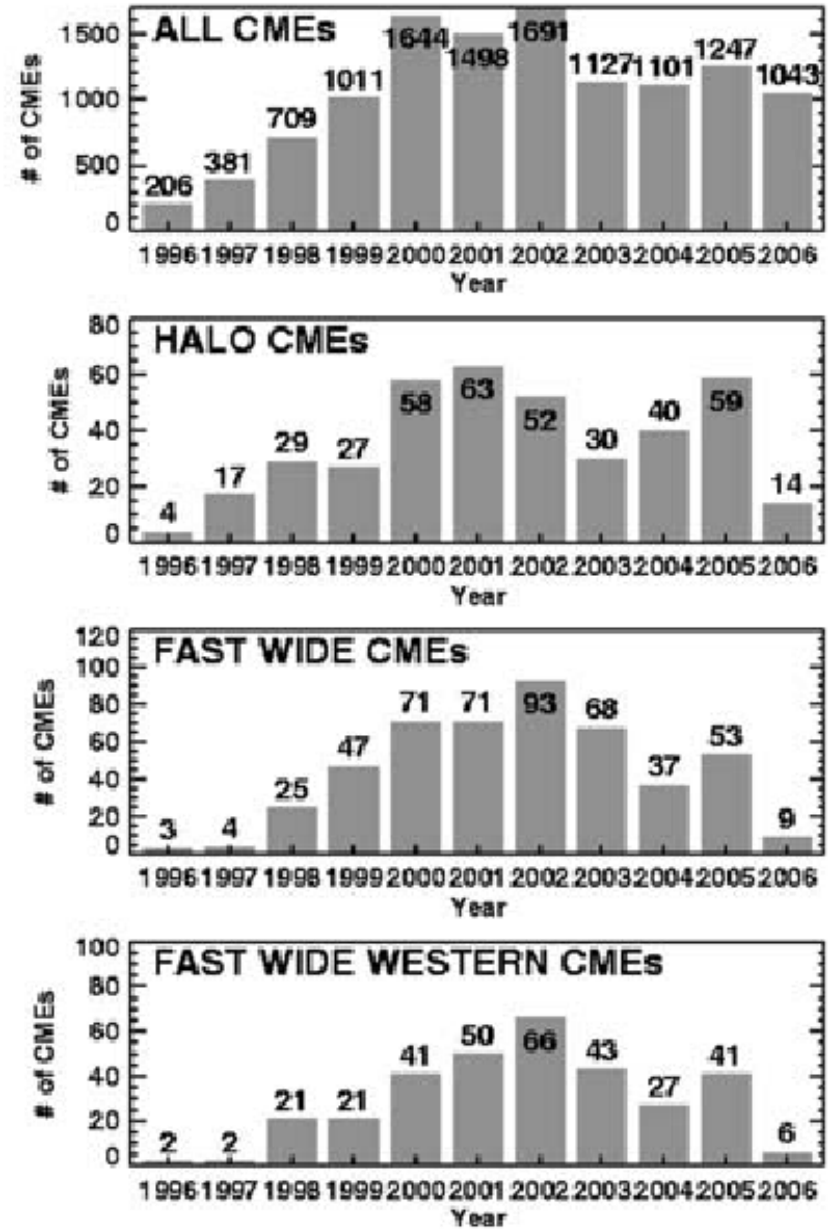
(Gopalswamy et al., 2010)

[SOHO LASCO CME Catalog]

Annual number of different CMEs

Cumulative distribution of CME speeds

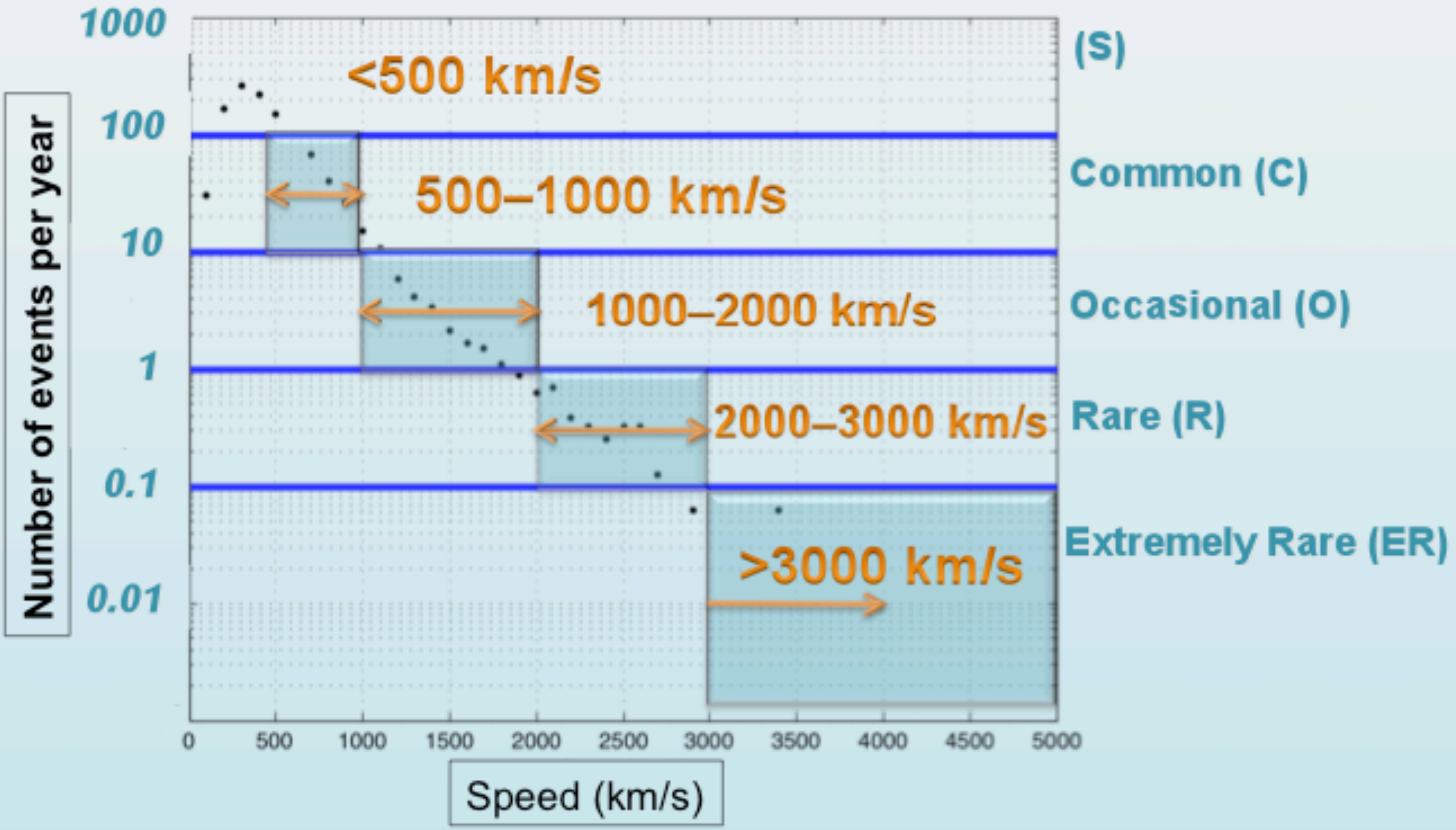




(Gopalswamy et al., 2010)

http://swrc.gsfc.nasa.gov/main/score

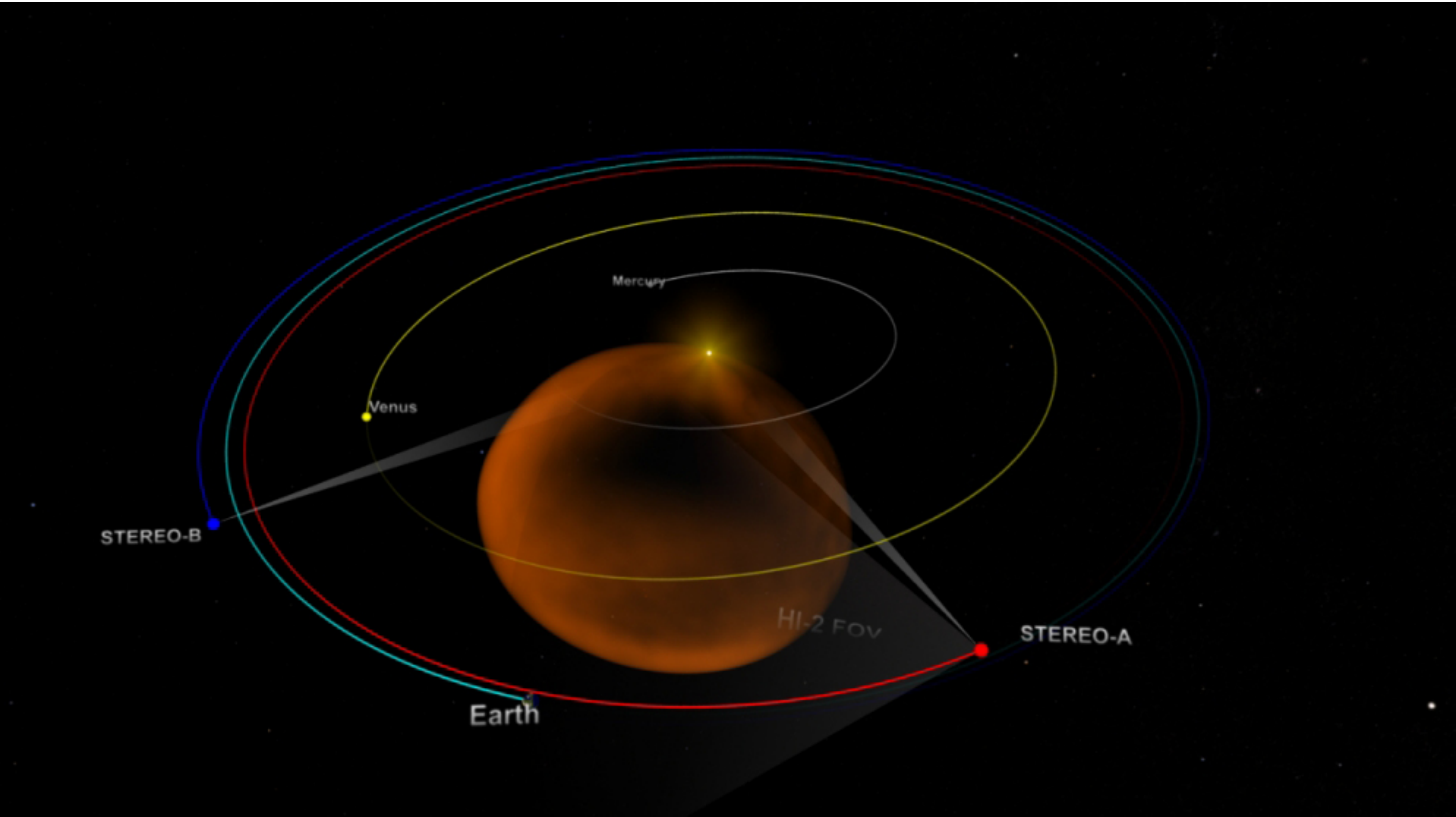
NASA GSFC Space Weather Research Center
CME Types (SCORE scale based on speed)



* Data: CDAWeb SOHO Lasco CME Catalog (linear speed)

The two STEREO spacecraft observe the sun from two viewpoints

View the STEREO spacecraft orbits movie:
[*https://www.youtube.com/watch?v=VzhMvEkK0gA*](https://www.youtube.com/watch?v=VzhMvEkK0gA)

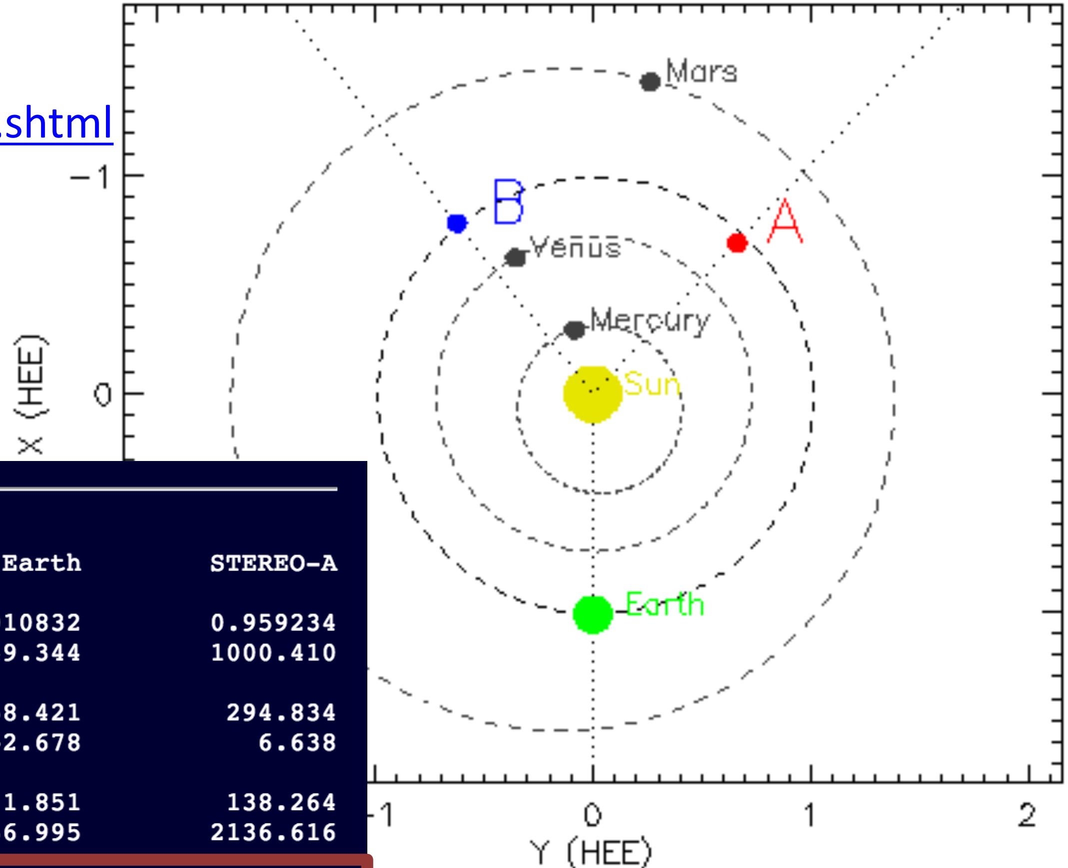


Where is STEREO?

http://stereo-ssc.nascom.nasa.gov/where.shtml

Click "STEREO Orbit Tool"

Longitude is measured
0 to 180˚ counterclockwise
0 to -180˚ clockwise



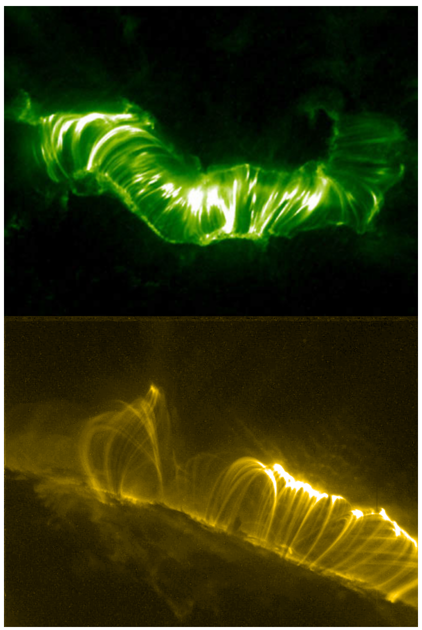
	STEREO-B	Earth	STEREO-A
Heliocentric distance (AU)	1.005357	1.010832	0.959234
Semidiameter (arcsec)	954.514	949.344	1000.410
HCI longitude	16.630	158.421	294.834
HCI latitude	-1.820	-2.678	6.638
Carrington longitude	220.059	1.851	138.264
Carrington rotation number	2137.389	2136.995	2136.616
Heliographic (HEEQ) longitude	-141.791	0.000	136.413
Heliographic (HEEQ) latitude	-1.820	-2.678	6.638
HAE longitude	92.490	234.029	10.422
Earth Ecliptic (HEE) longitude	-141.539	0.000	136.393
Earth Ecliptic (HEE) latitude	0.266	-0.000	0.051
Roll from ecliptic north	-0.335		0.055
Roll from solar north	6.612		3.094
Light travel time to Earth (min)	15.834		15.214
Separation angle with Earth	141.539		136.393
Separation angle A with B		82.067	

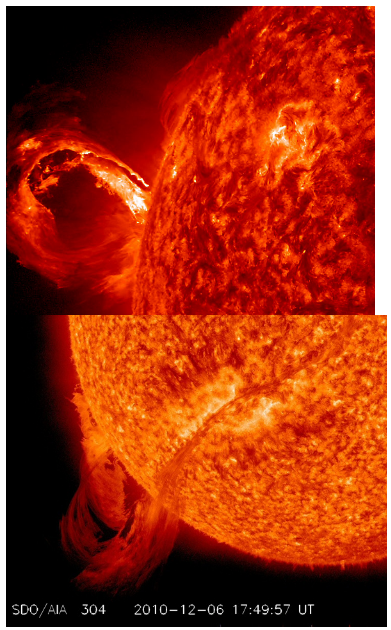
Date: 14 May 2013 Time: 21 : 00 UTC

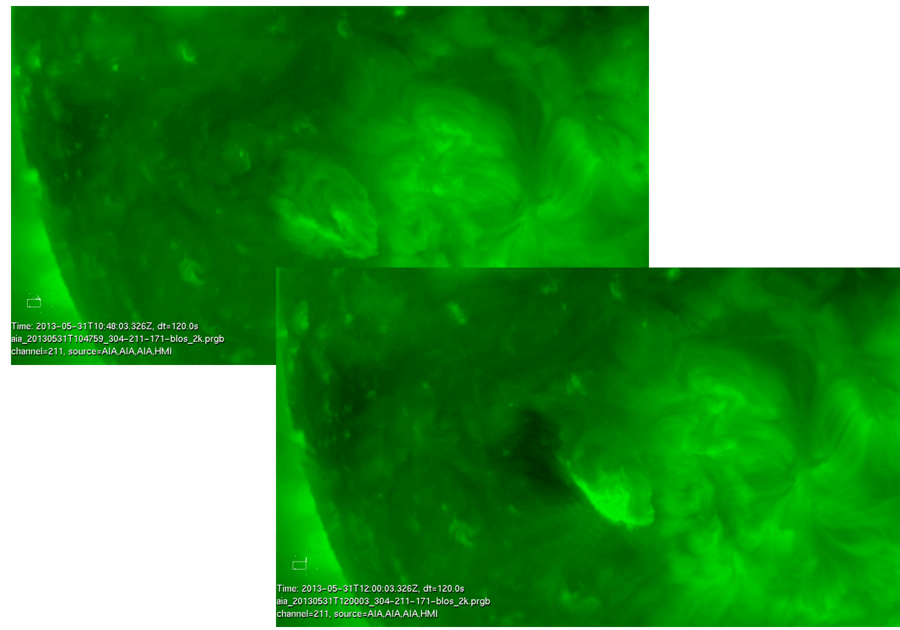
HEEQ:
Heliocentric Earth Equatorial
Z=North pole of solar rotation axis
X=intersection between solar equator and solar central meridian as seen from Earth

CME source locations/EUV lower coronal signatures of CMEs

* CMEs can originate from active regions and/or from filament eruptions.
* Some CMEs are associated with flares.
* EUV signatures include post eruption arcades, rising loops, coronal dimming, and prominence eruptions (click for example movies).







post eruption arcade   prominence eruption   coronal dimmings.

filament eruption

Important! Always determine the source location of every CME you analyze.
This can help you decide which coronagraph combinations to choose, and assess the accuracy of the CME parameters you obtain.

Sun Primer: Why NASA Scientists Observe the Sun in Different Wavelengths

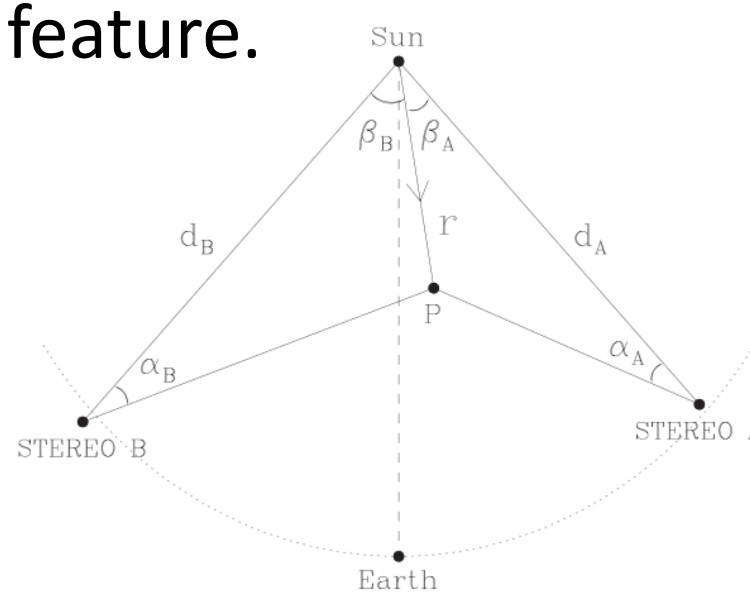
Geometric Triangulation

- Measuring the **same feature** (assumption) in two coronagraphs and using simple geometric relations to derive CME position and speed
- Observations are integrated line-of sight information through a 3D structure – projection effects, and scattering amplitudes impact the feature being measured!
- Note: StereoCAT does not use the edge locations (width) when triangulating the feature.

$$\frac{r \sin(\alpha_A + \beta_A)}{\sin \alpha_A} = d_A,$$

$$\frac{r \sin(\alpha_B + \beta_B)}{\sin \alpha_B} = d_B,$$

$$\beta_A + \beta_B = \gamma,$$



CME analysis Procedure with StereoCAT

* Identify the CME and the start time. (The CME start time is the time it is first observed by any of the four coronagraphs)
* Observe all available coronagraph images in motion. Look for the same CME leading edge feature in various spacecraft.
* Look at EUV images in motion near the CME start time and identify the source location and any lower coronal signatures (post eruption arcade, dimming, rising loops, filament eruption).

Go to StereoCAT: http://ccmc.gsfc.nasa.gov/analysis/stereo/

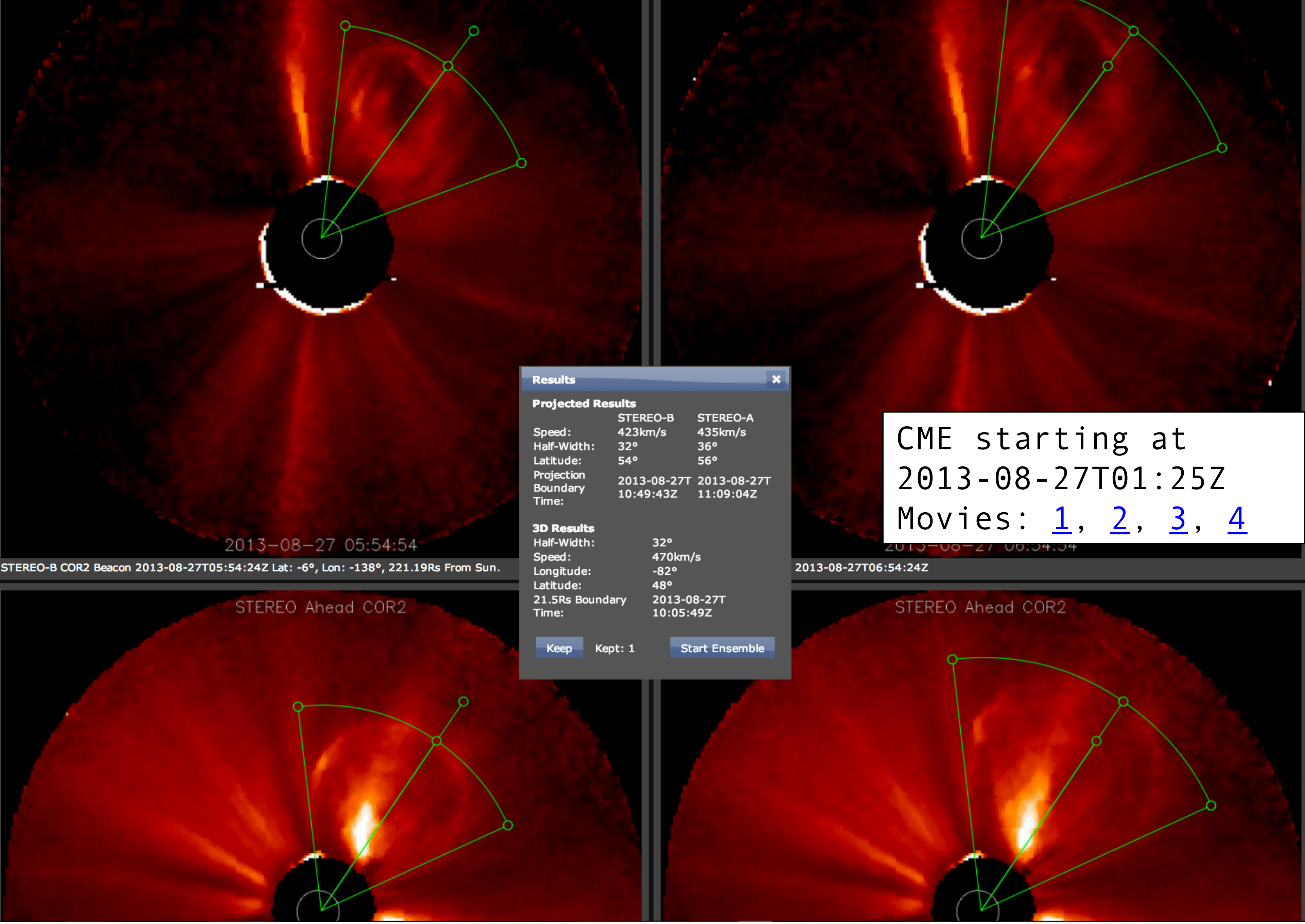
* Select two overlapping times for each spacecraft pair available. Times should be around 45-75 minutes apart, and try to choose times just before the CME leading edge has left the field of view. It is useful to refer back to the CME movies while selecting images.
* Perform plane of sky measurements CME leading edge and obtain triangulation results if appropriate. Determine final CME parameters (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).

Resources & iSWA layouts

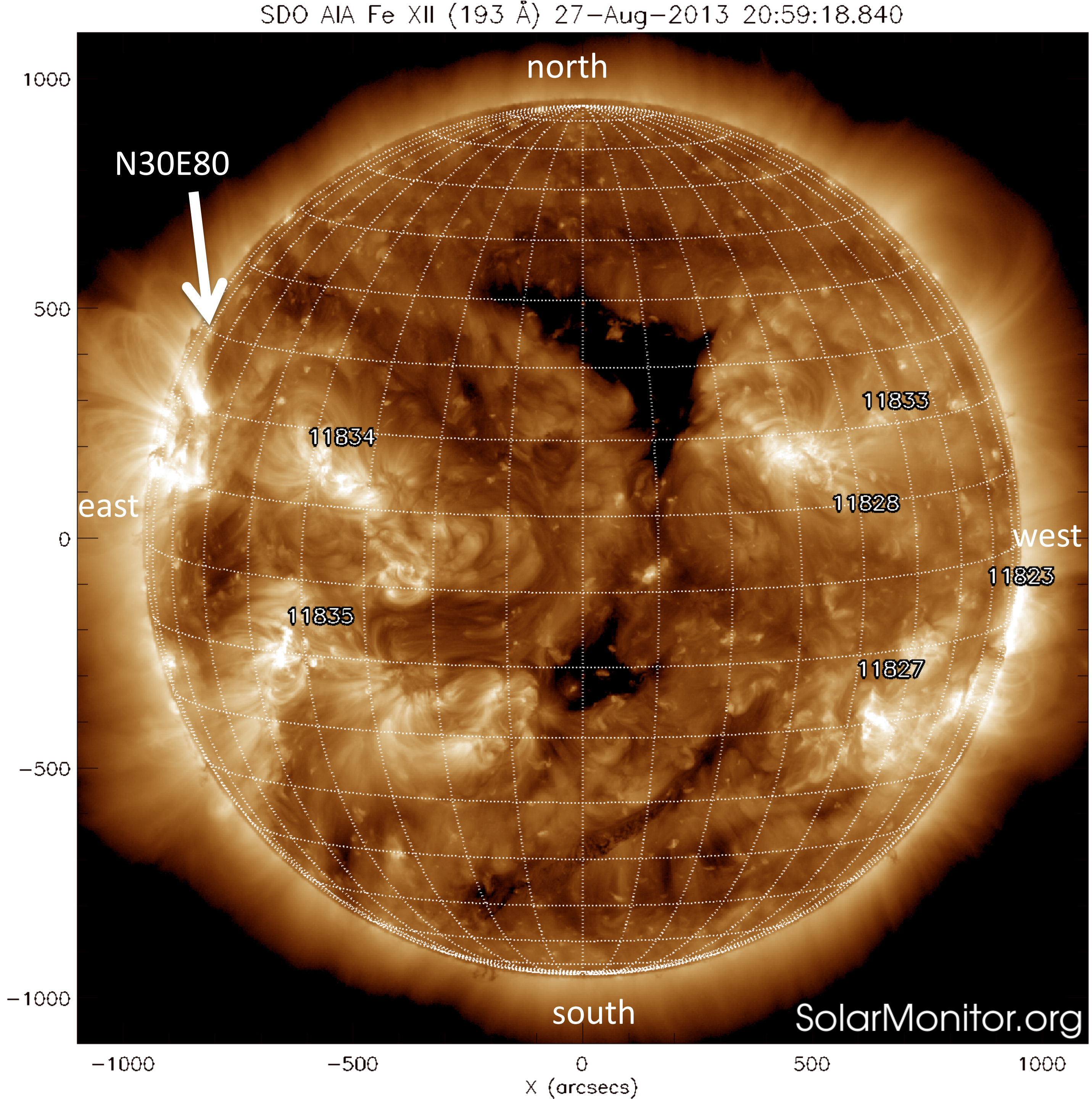
* *StereoCAT: http://ccmc.gsfc.nasa.gov/analysis/stereo/*
* *40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK*
* *Where is STEREO? http://stereo-ssc.nascom.nasa.gov/where.shtml and http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif*
* *Solar Images with grid overlays http://www.solarmonitor.org/*

CME analysis with StereoCAT tips/notes

* Make sure you are measuring the same feature in each spacecraft.
* If you cannot see the leading edge of the CME in image (halo), then it is not appropriate to use the triangulation method. In this case, estimate the plane of sky speed. It may be cautiously used for an asymmetric halo.
* Don't forget to determine the source location and signatures. Use these to assess the accuracy of your results (which spacecraft pairs will give the best results), or to derive the radial velocity from the plane of sky speed.
* Measure each CME about 10 times with various time and spacecraft pairs to get a feel for the parameters and the measurement error.
* The two selected times should be around 45-75 minutes apart for each spacecraft.
* The time between each spacecraft pair should be less than 10 minutes.
* Keep in mind that the goal is to determine the parameters at 21.5 Rs, not necessarily the fastest or earliest speed. Try to choose times just before the CME leading edge is closest to 21.5 Rs.
* Bear in mind that plane of sky speeds should always be lower than the derived radial velocity.



Example of a two-timepoint measurement *(click here to see in StereoCAT)*



You can determine the source region coordinates using a grid overlay from solarmonitor.org or the magnetic connectivity cygnet in iSWA. (Each grid cell is 10 degrees).

Remember that east is to the left!

StereoCAT: Single spacecraft mode

* If data from only one spacecraft is available, first measure the plane of sky speed

* Use the CME source location, signatures and qualitative information from other coronagraphs to determine the CME longitude

* Using this longitude, determine the angle the CME makes with the plane of sky (positive towards observer).

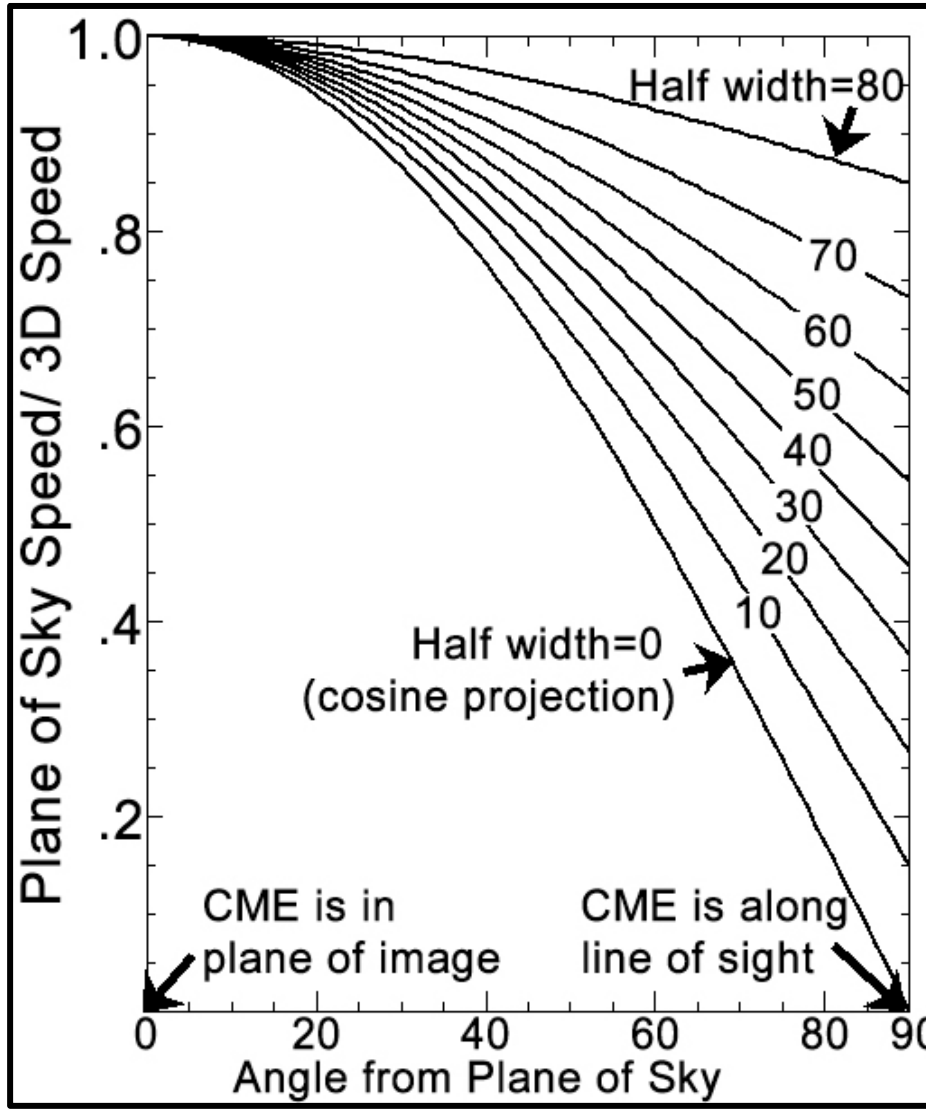
* If this angle is < 30 deg enter it at the bottom of the measurement screen, which does a simple cos(theta) approximation.

* If the angle compared to the plane of sky is larger, or the CME is very wide, use the CME Projection Graph to determine the approximate 3D speed.

    ○Use your width and source longitude to look up the ratio of the plane of sky speed to the true speed on the y axis.

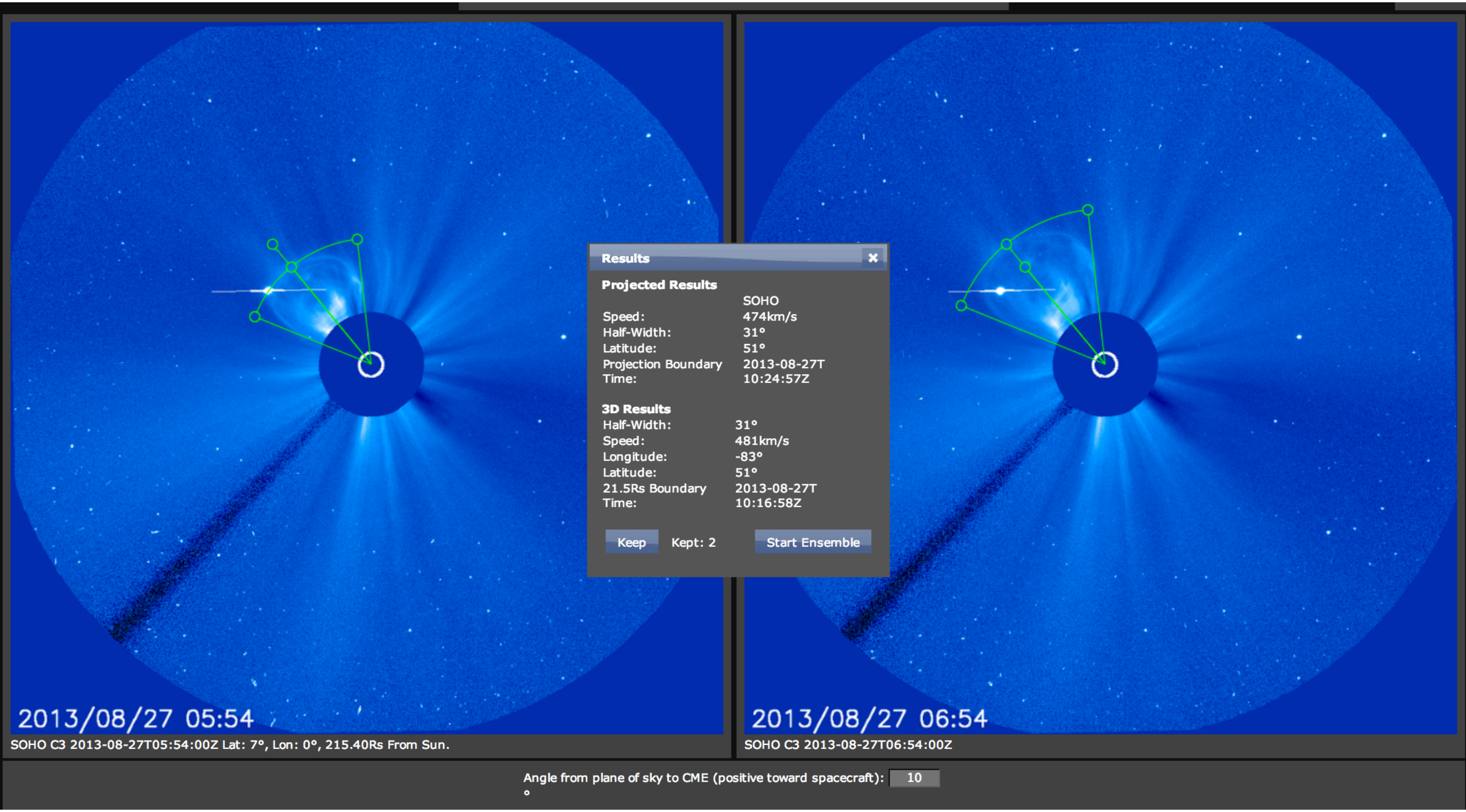
    ○ Divide your measured plane of sky speed by the ratio you looked up to obtain the true 3D speed.

CME Projection Graph



EXAMPLE in StereoCAT (or next slide)

Example of a single spacecraft two-time point measurement [(click here to see in StereoCAT)]

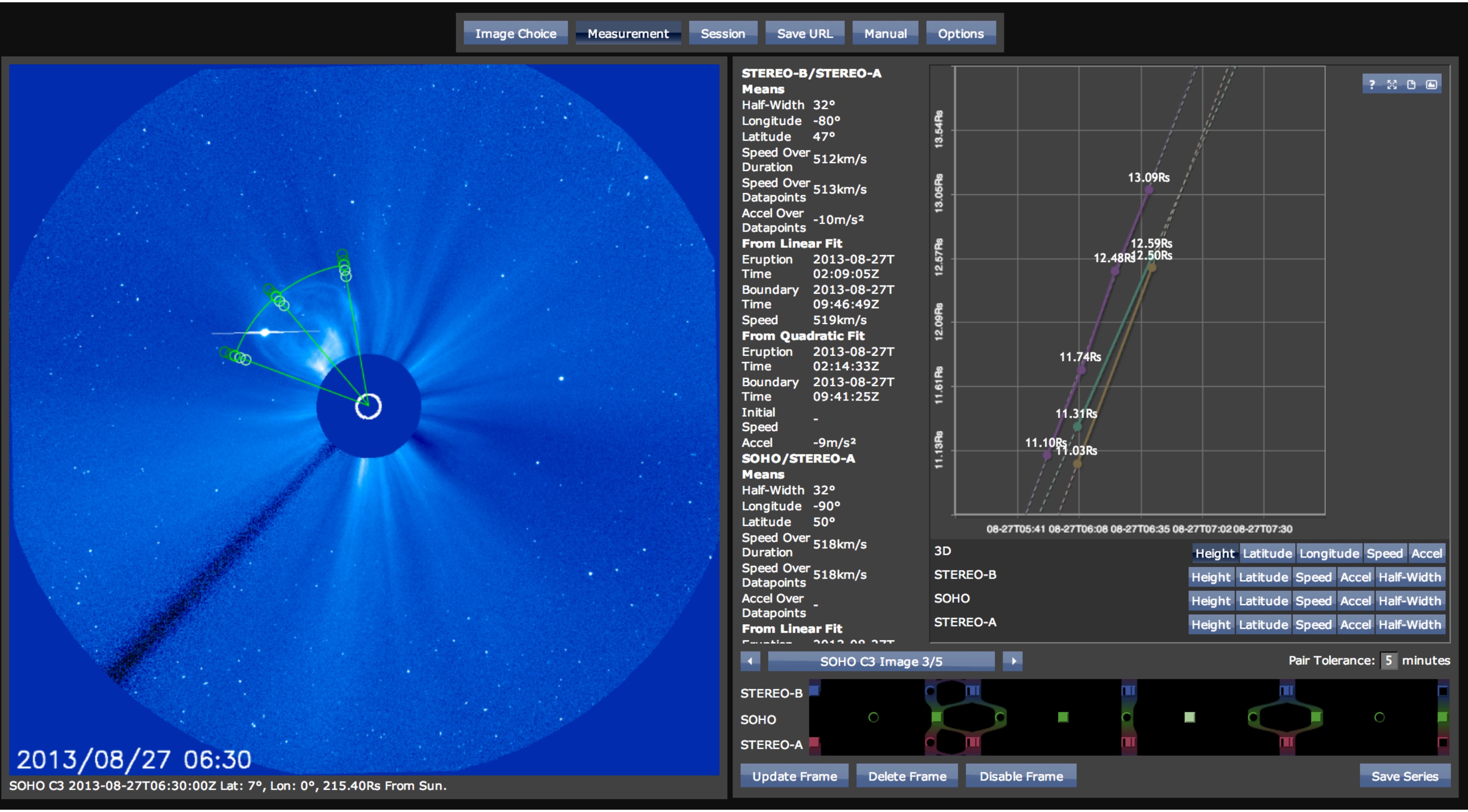


CME starting at
2013-08-27T01:25Z

Advanced Users: StereoCAT Frameseries mode

* The same procedure and factors apply to frameseries mode. This mode allows you to measure multiple coronagraph images at once to create a height-time plot, see the manual for usage details.
* As usual, be careful about the spacecraft pairs you use. By looking at the different graphs, you can see what the plane of sky heights and triangulated heights are for each measurement. This can help you determine when the triangulation is not accurate.
* This mode offers a linear fit, quadratic fit, and an average over all points. All of these results are dependent on which points you measure and how long your time range is. Be sure to carefully study all information under "Frameseries Results", and compare to your two-timepoint measurements.

Example of frameseries measurement *(click here to see in StereoCAT)*



CME starting at
2013-08-27T01:25Z

CME Analysis Resources & iSWA layouts

* StereoCAT: http://ccmc.gsfc.nasa.gov/analysis/stereo/

* 40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK

* Where is STEREO? http://stereo-ssc.nascom.nasa.gov/where.shtml

and http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif

* Solar Images with grid overlays http://www.solarmonitor.org/

* http://cdaw.gsfc.nasa.gov/movie/

CME assignment zero (in-class workshop)

For the CMEs listed below, follow the CME analysis procedure described in the lesson and also submit answers to the following questions for each CME:

```
HW#0 CMEs starting at
1) 2014-05-12T12:18Z
2) 2012-10-05T03:24Z
3) 2012-07-12T16:54Z
4) 2013-02-26T14:06Z
```

Resources & iSWA layouts

* *StereoCAT: http://ccmc.gsfc.nasa.gov/analysis/stereo/*
* *40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK*
* *Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif*
* http://cdaw.gsfc.nasa.gov/movie/
* *Solar Images with grid overlays http://www.solarmonitor.org/*

Fill out the form: **https://tinyurl.com/y3mlteqm**

a) What is the source location for this CME? (list the location e.g. N15E20, instrument/wavelength, and time of the observation).

b) Describe the EUV lower coronal signature for this CME (e.g. flare, post eruption arcade/loops, rising loops, dimming, filament eruption).

c) Is the CME a halo in any of the coronagraphs? If so, is it moving away from or towards the observer?

d) Which coronagraph instrument first observed the CME at the start time?

e) What are your final CME parameters (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).

f) Compare your EUV source location obtained in (a) with the parameters obtained in (e). Discuss why they might be different.

g) Submit your “Save URL” of your measurements.

Slide link summary

Resources & iSWA layouts
* CME analysis tool: http://ccmc.gsfc.nasa.gov/analysis/stereo/
* 40 Frame coronagraph and EUV movies http://go.nasa.gov/16bTvzK
* Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif
* http://cdaw.gsfc.nasa.gov/movie/
* Solar Images with grid overlays http://www.solarmonitor.org/

SW REDI website

http://ccmc.gsfc.nasa.gov/support/SWREDI/swredi.php

iSWA http://iswa.gsfc.nasa.gov

Example CME movie

http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=stb_cor2&img2=sta_cor2&stime=20120712_1500&etime=20120712_2000

http://helioviewer.org/?movieId=zZv95 http://helioviewer.org/?movieId=tZv95

Helioviewer solar visualization tool http://www.helioviewer.org/

SOHO LASCO CME Catalog http://cdaw.gsfc.nasa.gov/CME_list/

SWRC SCORE CME scale http://swrc.gsfc.nasa.gov/main/score

STEREO orbit movie https://www.youtube.com/watch?v=VzhMvEkK0gA

Sun Primer: Why NASA Scientists Observe the Sun in Different Wavelengths

http://www.nasa.gov/mission_pages/sunearth/news/light-wavelengths.html

EUV lower coronal signatures of CMEs movies

post eruption arcadehttp://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=sta_e195&img2=sta_cor2&stime=20130526_1500&etime=20130527_0000

prominence eruptions http://go.nasa.gov/19Dni3v

http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=lasc2rdf&img2=sdo_a304&stime=20130430_2200&etime=20130501_0800

filament eruptions http://go.nasa.gov/12qcWDO

http://www.lmsal.com/hek/gallery/podimages/2013/06/01/pod_malanushenko_anna_2013-06-01T02:24:03.851/anny_AIA-304_20130531T113203-20130531T185203_120s_made_20130601T022253_720p.mpg

coronal dimmingshttp://www.lmsal.com/hek/gallery/podimages/2013/06/01/pod_malanushenko_anna_2013-06-01T00:52:07.870/anny_AIA-211_20130531T094003-20130531T145203_120s_made_20130601T005102_720p.mpg

http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=stb_cor2&img2=stb_e195&stime=20120527_0300&etime=20120527_1600